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# Diffuse Ceiling Inlet Systems and the Room Air Distribution

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## SUMMARY

A diffuse ceiling inlet system is an air distribution system which is supplying the air through the whole ceiling. The system can remove a large heat load without creating draught in the room. The paper describes measurements in the case of both cooling and heating, and CFD predictions are given for the heating case.

## INTRODUCTION

This paper describes a new air distribution system which is able to remove a large heat load from a room without creating thermal discomfort in the occupied zone of the room [1]. Preliminary experiments show that the system can remove a larger heat load than other systems, as e.g. mixing ventilation, displacement ventilation and vertical ventilation (active displacement ventilation), [2]. The whole ceiling is the supply opening because air is supplied through standard acoustic ceiling elements and through the slots between the ceiling elements. It is characteristic of this type of air distribution system that it is the heat sources in the room that generate the air flow pattern in the room and the draught. Few examples of this system are known in comfort ventilation, but it is used extensively in livestock buildings.

Figure 1 shows the design chart for a typical system. It indicates the limit of the flow rate  $q_o$  and the temperature difference between return and supply  $\Delta T_o$  giving a draught of 0.15 cm/s in the occupied zone [1]. The product of  $q_o$  and  $\Delta T_o$  is constant, which is typical of all systems with low supply velocity where heat loads generate the flow in the room.

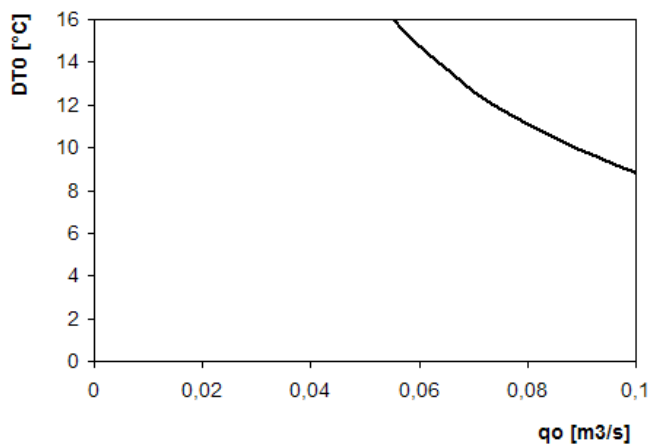


Figure 1. Design chart for a room with diffuse ceiling inlet.

This paper examines the details of the system, as e.g. test of new ceiling elements compared to the ceiling in [1], test of a new office layout, test of return opening location, and especially tests of some situations where the system is used for heating. The heating situation is studied both by full-scale experiments and by Computational Fluid dynamics (CFD).

All the experiments are made to test this application for a new 8000 m<sup>2</sup> administration building made for Videx A/S, Denmark.

## FULL-SCALE EXPERIMENTS AND CFD PREDICTIONS

The system is tested in a full-scale room with the length, width and height equal to 4.1 m, 3.2 m and 2.45 m, respectively. Both cooling (in a general situation), and heating (for the night situation) are tested.

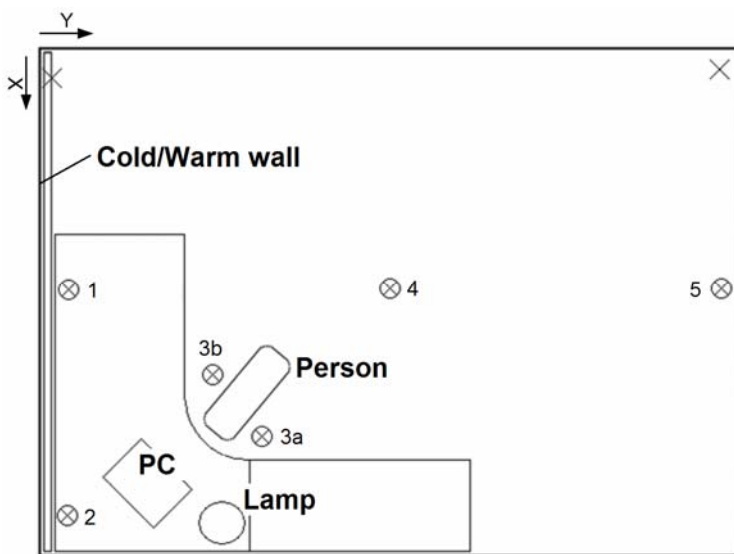


Figure 2. Full-scale room with location of the heat loads, which are a wall (cold/warm), a manikin, a computer and a lamp.

Figure 2 shows the layout of the office with the person as a heated manikin, a PC and a lamp. The numbers indicate the positions of the measured vertical temperatures. The cold/warm wall is represented by a plastic folio where cold or warm air can be circulated to represent a cold window during winter or a hot window during the summer, see figure 3.

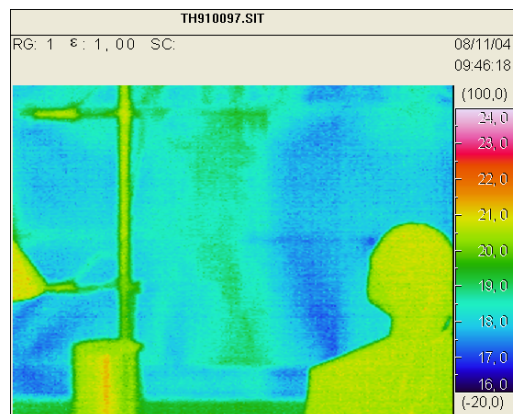
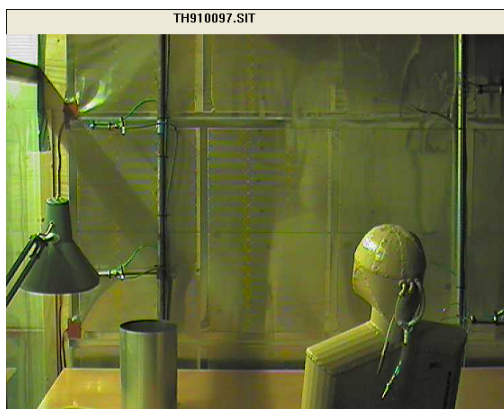


Figure 3. Cold/warm wall and a thermographic picture of the wall as a cold wall.

The air is supplied above the diffuse ceiling in the right side of the room (close to position 5). The exhaust opening can be located at different positions, and experiments are made with a position in the upper right corner just below the ceiling or below the desk in the opposite corner close to the floor. Figure 4 shows the supply duct, the diffuse ceiling and the return opening. The flow from the diffuse ceiling is mainly taking place through small slots and openings between the support of the acoustic ceiling and the ceiling elements, and to some extent through the elements.



Figure 4. Supply duct above the diffuse ceiling (the acoustic ceiling elements are removed in the photo), the diffuse ceiling and the movable return opening.

The room in figure 2 is only one quarter of the full room in the Widex office building. The experiments are therefore extended by CFD predictions for the full room with the dimensions, length, width, height equal to 7.2 m x 10 m x 2.7 m. The CFD predictions are focused on the heating situation. Figure 5 shows the geometry with an indication of the boundary conditions at the ceiling, which consists of a number of slots with a size of 2 cm and a length of 8.2 m. This inlet geometry gives a flow in the vicinity of the ceiling which corresponds to the measured velocity conditions. The supply air velocity is 0.102m/s (airflow rate of 3.5 h<sup>-1</sup>), and the supply air temperature is 27 °C. The heat flux through the window in winter is -40.8 W/m<sup>2</sup> and -5.1W/m<sup>2</sup> for the outer wall, which is calculated according to the Danish design criteria with a room air temperature of 22 °C, and an outside temperature of -12 °C. The boundary conditions at the other solid surfaces are adiabatic.

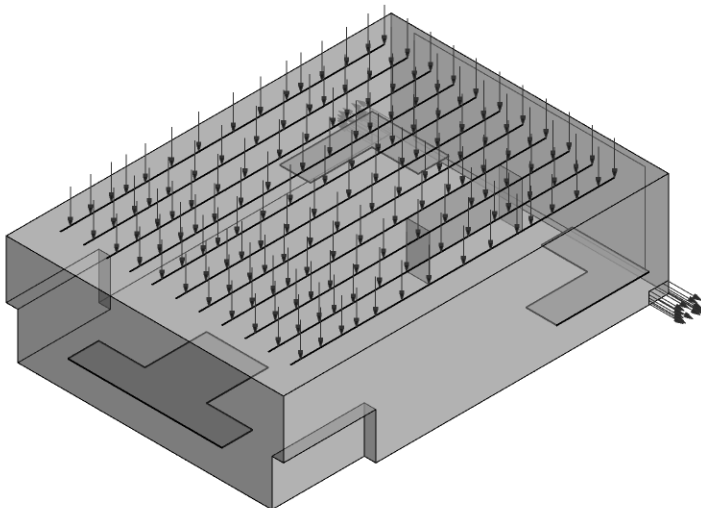


Figure 5. Geometry of the CFD predictions of a room with diffuse ceiling inlet.

## RESULTS AND DISCUSSION

One smoke experiment and three comfort experiments as well as one CFD prediction are carried out. The comfort experiments consist of one cooling experiment ( $8 \text{ h}^{-1}$ ) and two heating experiments ( $3.5$  and  $6.0 \text{ h}^{-1}$ ), and the CFD experiment covers the heating situation in a four times larger room without any internal heat load.

### Smoke experiment

The smoke experiments are made for both cooling and heating, and they are made for air change rates from  $3.5$  to  $8.0 \text{ h}^{-1}$ . It is shown that it is the internal heat sources that generate the flow and thus the mixing and draught in the occupied zone. It is also shown that the level of draught in the room is low, which is also documented in [1].

The air is supplied to the room through small slots between the sound absorbing elements and the support of these elements. The smoke experiments show that high velocities with high entrainment take place in microjets below the ceiling and up to  $0.5 \text{ m}$  down into the room. Therefore it is appropriate with a distance of at least  $0.5 \text{ m}$  from the occupied zone to the ceiling surface.

Experiments with different locations of the return opening show that the location is, as expected, of minor importance to the air distribution pattern.

### Comfort experiment, cooling case, $8 \text{ h}^{-1}$

The measurements of temperature and velocity distribution indicate a sufficient level of thermal comfort in the office, although the heat load and air change rate are high. Vertical temperature gradients in the room, figure 6, are small and the temperatures are at all positions between  $22.5^\circ\text{C}$  and  $25.0^\circ\text{C}$ . There is a horizontal gradient in the room with the highest temperatures in the right side of the room, figure 2, while positions close to the warm (window) wall have slightly lower temperatures. The return temperature is equal to  $22.6^\circ\text{C}$ .

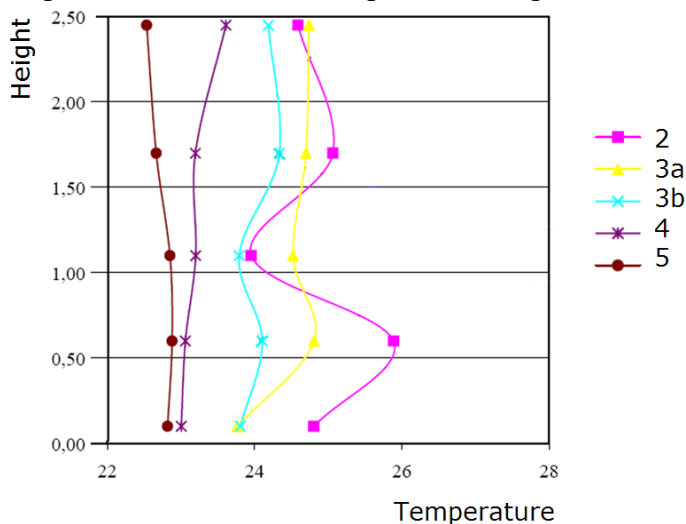


Figure 6. Vertical temperature gradients in the room. The positions 2 to 5 of the vertical measuring lines are shown in figure 2.

It is not possible to obtain any indication of unstable flow in the room, although heat loads are cooled from above with cold air with a minimum of momentum flow.

### Comfort experiment, heating case, 3.5 and 6.0 h<sup>-1</sup>

The heating case demonstrates a night situation without any heat load in the room but with the cold window wall. The idea with the heat supply is to maintain comfort conditions in the room until people show up at work. It is obvious that the situation with the supply of heated air from above creates a vertical temperature gradient in the room, and the absence of heat loads in the occupied zone also minimises the mixing flow in the room. Figures 7A and B show that the gradient is acceptable, and measurement of velocities does also indicate an acceptable level of thermal comfort. The temperature gradient at position 1, close the cold wall, shows a low level of the temperature, which is also to be expected. The return temperature is equal to 22.6 °C and 22.0 °C in the two cases.

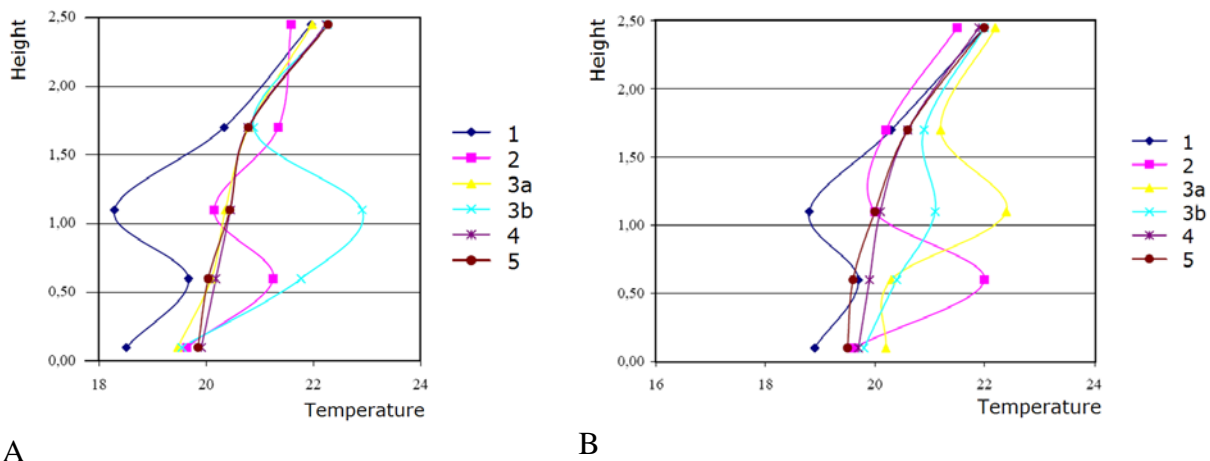


Figure 7. Vertical temperature gradients in the heating case. A) 3.5 h<sup>-1</sup> and B) 6.0 h<sup>-1</sup>. The positions 1 to 5 of the vertical measuring lines are shown in figure 2.

In this kind of heating case we will always recommend the use of a convector or floor heating for the support of heat.

### CFD predictions for the full room

The heating situation is the most interesting situation with respect to comfort. Therefore the experiments are extended by CFD simulations in the full room, which is four times as large as the full-scale room shown in figure 2. The room is without any internal heat load in order to study the situation with a maximum vertical temperature gradient.

The CFX11.0 software is used for the predictions, and the geometry is designed by 433,935 grid points in a structured grid.

A high resolution numerical scheme with blend factor values is used. In flow regions with low variable gradients, the blend factor is close to one for accuracy (second-order accuracy). In areas where gradients change sharply, the blend factor is close to zero to prevent overshoots and

undershoots and to maintain robustness (first-order accuracy). The predictions are based on time-dependent RANS equations, and the results are presented in  $T=1800s$ . It was not possible to obtain a converged solution with steady state equations.

Figure 8 shows a typical prediction of the velocity distribution in the room. The high velocity area above the occupied zone is obvious in the figure.

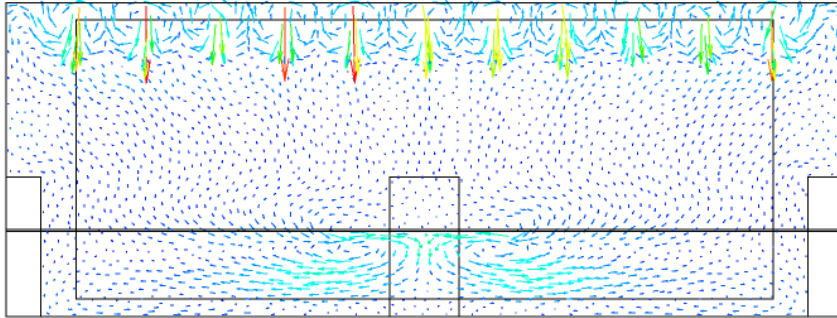


Figure 8. CFD predictions of the velocity distribution in the office room with diffuse ceiling inlet.

The prediction of the vertical temperature distribution in the office indicates larger vertical gradients than the ones measured in the full-scale room. The temperature in figure 9 is  $27^{\circ}\text{C}$  at the ceiling, and  $23^{\circ}\text{C}$  at floor level.

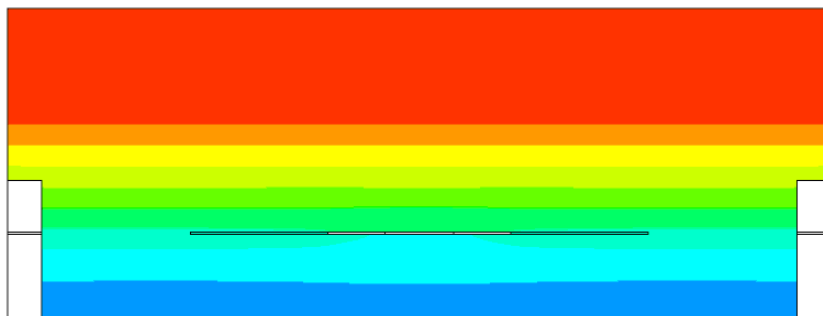


Figure 9. CFD prediction of the temperature distribution.

## CONCLUSIONS

The experiments show that the diffuse ceiling inlet system is working well in the case of cooling. There is no indication of any unstable flow situations, although cold air is supplied with a low momentum flow above warm air in the occupied zone.

The system is also working in a satisfactory way when it is used in the heating situation. Some low temperatures close to the cold surface in the experiments, and the indication of large vertical temperature gradients in the CFD predictions show that in this case areas with low temperatures may exist. On the other hand, smoke experiments show that a few heat sources generate sufficient mixing flow in the room to obtain thermal comfort. It should be recommended to use the system together with convectors in the heating mode.

Smoke experiments show that the location of the return opening is of minor importance.

The return temperature is lower than the averaged room temperature in the cooling case, and higher than the room temperature in the heating case. This means that the temperature effectiveness is slightly below 1.0 in both cases.

## **ACKNOWLEDGEMENT**

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